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Increasing corn yield with no-till cropping systems: a case study in South Dakota

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Abstract

No-till practices have improved crop yields in the semiarid Great Plains. However, a recent assessment of research studies across the globe indicated that crop yields are often reduced by no-till. To understand this contrast, we examined corn yields across time in a no-till cropping system of one producer in central South Dakota to identify factors associated with increased yield. The producer started no-till in 1990; by 2013, corn yield increased 116%. In comparison, corn increased only 32% during this interval with a conventional, tillage-based system in a neighboring county. With no-till, corn yields increased in increments due to changes in management. For example, corn yield increased 52% when crop diversity in the rotation was expanded from 2 to 5 crops. A further 18% gain in yield occurred when dry pea was grown before corn in sequence. Nitrogen (N) requirement for corn is 25% lower in no-till compared with a tillage-based rotation. Furthermore, phosphorus (P) fertilizer input also has been reduced 30% after 20 yr of no-till, even with higher yields. Our case study shows that integrating no-till with crop diversity and soil microbial changes improves corn yield considerably. This integration also reduces need for inputs such as water, N and P.

Key words: conservation agriculture, crop diversity, management tactics, soil microbial community, reduced inputs

Introduction

No-till practices are widely used for crop production in the US Great Plains. The initial stimulus to adopt no-till in this region was to minimize soil erosion and improve water relations in a semiarid climate (Peterson et al., 1993). Improving water relations led to more stability with crop yields during drought years. With time, producers gained additional benefits with no-till, such as increased crop yields, soil organic matter (SOM) levels and soil aggregation (Triplett and Dick, 2008).

To encourage adoption of no-till globally, the Food and Agriculture Organization (FAO) of the United Nations developed the concept, conservation agriculture (FAO, 2015). Conservation agriculture is based on three principles: (1) direct seeding of crops with minimum soil disturbance (no-till), (2) permanent soil cover by crop residues or cover crops and (3) crop rotation. The FAO views conservation agriculture as critical for achieving sustainability of global agriculture.

However, a recent global assessment of crop yields comparing no-till with tilled systems showed that no-till reduces crop yield (Pittelkow et al., 2015). This assessment, comparing 48 crops from 612 research experiments in 63 countries, found that crop yield is 12% less in no-till. The negative impact of no-till on crop yield was lessened if systems included residue preservation on the soil surface and crop rotation, yet yields were still less than tilled systems. The authors noted that results vary with climatic conditions; no-till could be favorable for yield in dry climates if combined with residue management and crop rotations. Palm et al. (2014), also reviewing conservation agriculture at a global perspective, noted that crop response to no-till not only varies with climate but also with management.

Producers in central South Dakota consider no-till essential for crop production, and have found that crop yields in no-till greatly exceed expectations based on water and nutrient supply. Because of the negative trend noted in global assessments of no-till (Pittelkow et al., 2015; Palm et al., 2014), we examined corn (*Zea mays* L.) yield in a no-till operation in central South Dakota. Our goal with this case study was to explore aspects of management that may affect corn yield in no-till, and to gain insight for integrating no-till with conservation agriculture.

Materials and Methods

Corn yields on the Ralph Holzwarth farm in central South Dakota were evaluated across a 24-year interval, 1990–2013. Yield values were based on yield proofing data supplied to the USDA-NRCS (Holzwarth, 2015). Because no-till is the standard practice in Potter County where Ralph farms, we compared corn yields on the Holzwarth farm with production levels in Brookings County, SD, where tillage is the standard. The Holzwarth farm and Brookings County are 160 km apart but at the same latitude, have soils with similar organic matter (OM) levels (4%) and textures (loams to silt loams), and grow similar hybrid maturities of corn. Also, cropping practices in Brookings County have been consistent for these 24 yr, tillage-based corn–soybean rotation; no-till is rarely used. Brookings County yield data were county averages for dryland production during two intervals, 1990–1993 and 2008–2013 (NASS, 2015). Yield data during the 2008–2013 interval were compared between the Holzwarth farm and Brookings County with the *t*-test.

Changes in fertilizer input across time on the Holzwarth farm were based on personal records kept for specific fields. Data for nitrogen (N) and phosphorus (P) inputs were compared for corn grown during two intervals, 1990–1993 and 2008–2013. SOM levels in selected fields were determined with the loss on ignition method based on samples collected from the 0 to 20 cm depth. Analysis was conducted by a commercial soil testing laboratory (Ward Laboratories, Inc., Kearney NE), with the same fields sampled in 1990 and 2010.

A series of management changes were imposed during the 24-year assessment; corn yields were averaged across years following adoption of each management change to quantify its impact on yield. Yield responses were then related to possible biological changes based on research conducted in the Great Plains with no-till systems.

Corn Yield in the Holzwarth No-Till System

Ralph Holzwarth farms near Gettysburg, South Dakota where yearly precipitation averages 460 mm. Ralph began no-tilling (direct seeding with minimal soil disturbance) in 1990; during 1990–1993, corn yielded 4400 kg ha^{-1} in a winter wheat (*Triticum aestivum* L.)–corn–fallow rotation (Holzwarth, 2015). During 2008–2013, after 2 decades of no-till, corn yield averaged 9500 kg ha^{-1}, an increase of 116%. During 2008–2013, the average corn yield in Brookings County was 8700 kg ha^{-1} (NASS, 2015), or 9% less than on the Holzwarth farm (Table 1).

This yield comparison is somewhat surprising for two reasons. First, average precipitation in Potter County is 125 mm less than in Brookings County. Secondly, Ralph plants his corn at a lower density, 57,000 plants ha^{-1}, in contrast with densities of 78,000 plants ha^{-1} or higher in Brookings County. Thus, corn yielded 9% more on the Holzwarth farm with 22% less rainfall and 27% fewer plants. The range of yields during the 2008–2013 interval (Fig. 1) shows that the Holzwarth system was especially favorable for corn yields during low-yielding years such as 2008 and 2012.

We also compared county yield averages between Potter and Brookings Counties (NASS, 2015). No-till systems in Potter County were rapidly adopted between 2002 and 2008, and now occupy 95% of cropland. The county average for corn yield in 1990–1993 was 4250 kg ha^{-1}, or 35% less than Brookings County. During 2008–2013, corn yielded 6800 kg ha^{-1} in Potter County, or 25% less than Brookings County. We attribute this 10% gain in Potter County yield compared with Brookings County to the gradual improvement in soil functioning by no-till.

Considering yields between 1990 and 2013 in Brookings County, corn yield increased from 6600 kg ha^{-1} during 1990–1993 to 8700 kg ha^{-1} during 2008–2013 (NASS, 2015), a gain of 32%. This yield gain

Table 1. Agronomic summary of corn production on the Holzwarth farm in central South Dakota and in Brookings County, South Dakota.

	Holzwarth	**Brookings county**
Corn yield (kg ha^{-1})	9500	8700
Precipitation (mm yr^{-1})	460	585
Corn population (plants ha^{-1})	57,000	78,000
Management		
Tillage	No-till (20^{+} yr)	chisel plow, disking
Rotation	W–P–C–SB–O	C–SB

Yields averaged across 6 yr, 2008–2013.
W, winter wheat; C, corn; P, dry pea; SB soybean; and O, oat (Holzworth, 2015; NASS, 2015).

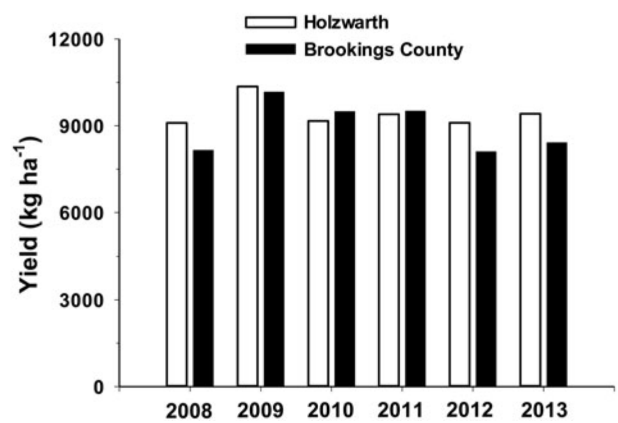

Figure 1. Corn yields at the Holzwarth farm compared with yields in Brookings County, 2008–2013. Yield means averaged across years did not differ between the Holzwarth farm and Brookings County, based on *t*-test. (Adapted from Holzwarth, 2015; NASS, 2015).

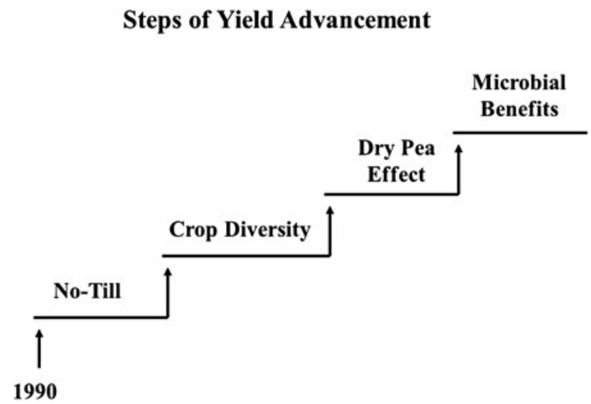

Figure 2. Management factors associated with yield gains of corn in the Holzwarth no-till cropping system in central South Dakota. No-till was started in 1990.

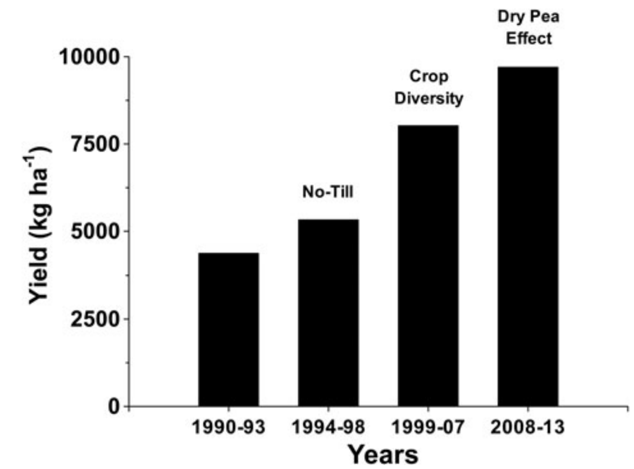

Figure 3. Changes in corn yield across time with the Holzwarth no-till cropping system in central South Dakota (Holzwarth, 2015). Yields recorded from 1990 to 2013. Bar labels refer to management changes associated with yield gain for that time interval.

likely relates to advances in hybrid genetics and improved pest management. However, the change in corn yield between 1990 and 2013 on the Holzwarth farm, 116%, was 3·5 times higher than in Brookings County. Two factors may contribute to this contrast in yield changes across time. First, no-till has been continuous since 1990 on the Holzwarth farm, whereas producers in Brookings County till to prepare a seedbed (Table 1). Secondly, Ralph uses more diverse crop rotations, such as winter wheat–dry pea (*Pisum sativum* L.)–corn–soybean [*Glycine max* (L.) Merr.]–oat (*Avena sativa* L.). Producers in Brookings County use a corn–soybean rotation.

Corn is more efficient in converting resources into grain with the Holzwarth no-till system; producing 45% more grain per plant than in Brookings County (Table 1). This improved efficiency may relate to management. Ralph observed that yield gains of corn were associated with management changes in his production system (Fig. 2). An initial gain in yield resulted from no-till and residue management increasing water supply. Diversifying the crop rotation led to a second yield gain, whereas a third gain in yield occurred when dry pea was grown before corn. Furthermore, crop yield increased even though need for inputs such as fertilizer are less, which he believes occurs because of enhanced microbial activity in the soil. In the following sections, we describe biological factors that may be associated with these steps of yield gain.

Steps of Yield Gain in the Holzwarth System

First step of yield gain: no-till and crop residues on the soil surface (Fig. 2)

For the first 4 yr of no-till, 1990–1993, corn yielded 4400 kg ha^{-1} (Fig. 3). During 1994–1998, corn yield averaged 5330 kg ha^{-1}, a gain of 21% which is attributed to improved water relations with no-till and residue management. Peterson et al. (1996), reviewing water relations with no-till, noted that crop residues on the soil surface reduce soil water evaporation, thereby increasing the quantity of precipitation stored in soil during non-crop intervals. Also, tilling soil increases soil water evaporation by exposing moist soil to air. In some years, an additional 5–8 cm of water can be stored in no-till compared with tilled systems during the interval between winter wheat harvest and corn planting.

Second step of yield gain: crop diversity (Fig. 2)

Because of improved water relations, Ralph expanded his rotation to include more crops, such as oat, soybean and sunflower (*Helianthus annuus* L.). In place of winter wheat–corn–fallow, his rotation was spring wheat or oat–winter wheat–corn–sunflower or soybean. Consequently, corn yield increased from 5330 kg ha^{-1} during 1994–1998 to 8030 kg ha^{-1} during 1999–2007, a gain of 52% (Fig. 3).

This yield gain is related to crop diversity suppressing plant diseases (Krupinsky et al., 2002). Long-term, no-till rotation studies in the Great Plains have shown that grain yield of corn can be 15–20% higher when corn is grown once every 4 yr compared with being grown once every 2 yr (Anderson, 2009; Beck, 2015). After-harvest residues of corn can be toxic to corn seedlings the following year, reducing growth and yield in monoculture corn (Anderson, 2011).

Higher corn yield in diverse rotations may also result from improved mycorrhizal relationships with corn roots, which increases nutrient uptake and use-efficiency, photosynthetic efficiency and stress tolerance in crops (Auge,

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2004). Mycorrhizal association with corn is enhanced because no-till (Helgason et al., 2010) and crop diversity (Brussaard et al., 2007) increase mycorrhizae density in soil. Crop diversity also leads to mycorrhizal species that are more beneficial for corn (Douds and Millner, 1999). Furthermore, eliminating fallow in the rotation increases mycorrhizae density in soil and subsequent colonization of corn roots (Smith and Smith, 2011).

Another factor improving corn yield is gradual improvement of soil health across time. No-till and crop residues on the soil surface increase soil porosity and water infiltration (Shaver et al., 2002; Liebig et al., 2004). Improved soil porosity is related to two factors. First, higher levels of SOM developed in the top layers of soil with no-till (Sherrod et al., 2005). SOM level in Holzwarth cropland increased from 2 to 4% after 20 yr of no-till. Secondly, no-till favors the fungi community in soil, which interacts with SOM to build soil aggregates and improve porosity (Rillig, 2004; Caeser-TonThat et al., 2011). A further benefit of higher SOM in soil is increased water storage capacity (Hudson, 1994).

Third step of yield gain: dry pea increased corn yield (Fig. 2)

In 2008, Ralph added dry pea to the rotation and observed an immediate 18% increase in corn yield (Fig. 3). This unique impact of dry pea on corn has also been observed in eastern South Dakota, where corn yielded 12–15% more following dry pea than following spring wheat, soybean or canola (*Brassica napus* L.) (Anderson, 2011). All four crops minimized yield loss observed with continuous corn due to root diseases and mycotoxins, but dry pea provided an additional gain in yield. Water supply for corn did not differ among preceding crops, nor did plant size or nutrient concentration in corn change with preceding crop (Anderson, 2012). Apparently, dry pea affects corn physiology to improve growth efficiency, thereby increasing corn yield with the same resource supply. A further benefit of dry pea is that corn can be grown at lower plant densities and still maintain yield. Corn yields the same at 52,000 plants ha^{-1} following dry pea as at 73,000 plants ha^{-1} following soybean or spring wheat; individual corn plants are more productive following dry pea (Anderson, 2011).

The dry pea effect on corn yield is attributed to rhizobacteria associating with crop roots. Lupwayi et al. (2004) found that dry pea can increase density of rhizobacteria in following crops, whereas Riggs et al. (2001) showed that corn yield increases with higher densities of rhizobacteria on its roots. Yield increases because rhizobacteria improve the resource-use-efficiency of crops. For example, photosynthesis efficiency of rice (*Oryza sativa*) is 12% higher when rice roots are inoculated with rhizobacteria (Peng et al., 2002). Rhizobacteria also increase nutrient uptake and drought tolerance in crops (Dobbelaere et al., 2003).

Potential fourth step of yield gain: microbial benefits (Fig. 2)

Ralph believes his next step of yield gain with corn and other crops will result from microbial benefits, as no-till and crop diversity favor the soil microbial community (Shaxson, 2006; Helgason et al., 2010). At a site 80 km north of the Holzwarth farm, a no-till system after 17 yr increased microbial biomass in soil almost 3-fold compared with a tilled rotation that included fallow (Liebig et al., 2004). Ralph is seeking to further increase microbial biomass with cover crops planted after harvest of winter wheat and oat. Cover crops increase microbial biomass by extending the duration of live plant growth during the growing season (Welbaum et al., 2004; Kabir, 2005). Greater microbial biomass in soil has been positively correlated with higher corn yield (Silva et al., 2010). Yield may further increase due to beneficial interactions between mycorrhizae and rhizobacteria (Artursson et al., 2006), as no-till increases density of both in soil (Welbaum et al., 2004; Helgason et al., 2010). In one experiment, the interaction between mycorrhizae and rhizobacteria increased grain yield of winter wheat 41% above a fertilized control (Maader et al., 2011). Also, mycorrhizae develop a mycelia network in no-till that persists across years, which enhances corn seedling growth and subsequent grain yield because of improved nutrient transport (Miller, 2000; Kabir, 2005).

Integrating no-till with increased microbial biomass and diversity improves soil functioning (Auge, 2004; Shaxson, 2006). In one long-term (23 yr) study, small grains yielded 15% more in no-till than with a tilled system, even when adequate nutrients were available (LaFond et al., 2011). One aspect of improved soil functioning is increased nutrient-use-efficiency due to microbial diversity (Brussaard et al., 2007). An intriguing trend with the Holzwarth system is that N need has declined across time. In 1990, Ralph applied 45 kg N ha^{-1} as fertilizer to corn in the winter wheat–corn–fallow rotation. In 2013, Ralph applied only 60 kg N ha^{-1}, even though corn yield more than doubled. Currently, Ralph calculates his N need based on 1·5 kg N 100 kg grain^{-1}, which is 25% lower than the 2 kg N 100 kg grain^{-1} value used for tillage-based systems (Gerwing and Gelderman, 2005). Less N fertilizer input is needed because no-till and crop diversity increase the N-supplying capacity of the soil with time (Soon and Clayton, 2002; Halpern et al., 2010). With a 9500 kg ha^{-1} yield goal, Ralph would apply 45 kg N ha^{-1} less than producers in a tilled system.

Ralph has also reduced P fertilizer inputs 30% in 2008–2013 compared with 1990–1994. This trend occurs because of increased organic pools of P and microbial enhancement of P availability for plants (Richardson and Simpson, 2011). For example, mycorrhizae increase crop capacity to use organic sources of P and N (Hamel, 2004). In the study that quantified the interaction between mycorrhizae and rhizobacteria (Maader et al., 2011), part of the 41% yield gain in wheat was attributed to improved P uptake and use-efficiency.

No-till is critical for conservation agriculture success in a semiarid climate

No-till, when integrated with diverse crop rotations, is transforming Great Plains cropping systems. For example, one goal of conservation agriculture is to develop farming systems that produce more food while using less resources (FAO, 2015). This goal can be achieved by enhancing beneficial interactions that occur among biodiversity and soil functioning (van Noordwijk and Brussaard, 2014). The Holzwarth system demonstrates this dynamic; corn yield doubled after 20 yr of no-till and crop diversity, yet need for N and P fertilizers decreased.

This yield gain with corn may appear to be an anomaly, but a similar gain in yield has occurred with winter wheat and no-till, diverse cropping systems, both on the Holzwarth farm and elsewhere in the semiarid Great Plains (Anderson, 2009). Winter wheat yields have also doubled compared with conventional, tillage-based systems in favorable environments, exceeding projected yields based on resource supply due to greater efficiency of the biological system in no-till.

Implications for Conservation Agriculture

Conservation agriculture does not define a level of crop diversity for rotations in their principles (FAO, 2015). Our case study shows that corn yield increased substantially when the rotation was expanded from 2 to 5 crops. Greater diversity provides more opportunities for favorable interactions among crops to enhance yield. An intriguing aspect of crop diversity is that the beneficial impact of a crop on following crops can persist for several years; small grain crops were still responding favorably to dry pea 4 yr after its appearance in the rotation (Kirkegaard and Ryan, 2014). The benefit of crop diversity can be further enhanced by including crop sequences that improve resource-use-efficiency. In addition to dry pea effect on corn growth, other sequences that improve water- or N-use-efficiency are winter wheat following either dry pea or lupin (*Lupinus angustifolius* L.) (Seymour et al., 2012), soybean following corn (Anderson, 2011) and sorghum [*Sorghum bicolor* (L.) Moench] following red clover (*Trifolium pratense* L.) grown as a cover crop (Sweeney and Moyer, 2004). Conservation agriculture may be more successful if rotations are comprised of several crops.

Conservation agriculture is based on three principles: no-till, residue preservation and crop rotation (FAO, 2015). It may be helpful if a fourth principle related to microbial management was identified. Yield gains in the Holzwarth system occur in a step-like fashion because no-till and crop diversity are needed first to accrue microbial benefits. Earlier, we noted that corn yields 45% more per plant in the Holzwarth system than the tilled system in Brookings County. We attribute this change in plant yield to favorable interactions among no-till, crop diversity and the soil microbial community. Scientists are developing management tactics to enhance soil microbial impact on crop productivity (Brussaard et al., 2007; Shennan, 2008). Integrating these tactics with other principles of conservation agriculture may improve success with no-till in climates other than semiarid.

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